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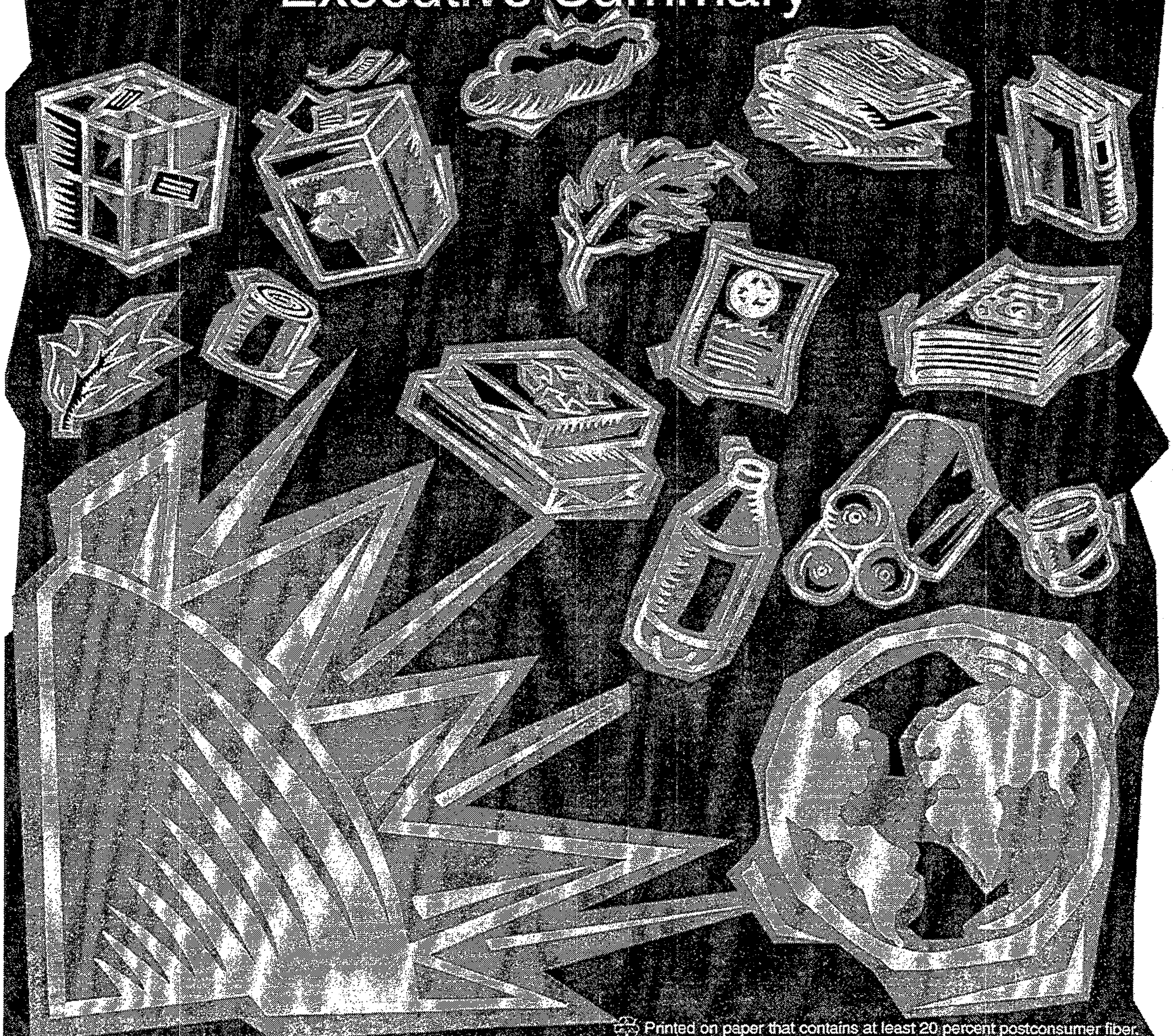
Greenhouse Gas Emissions From Management of Selected Materials in Municipal Solid Waste

Executive Summary



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GREENHOUSE GAS EMISSIONS FROM MANAGEMENT OF SELECTED MATERIALS IN MUNICIPAL SOLID WASTE

FINAL REPORT

Prepared for the U.S. Environmental Protection Agency
under EPA Contract No. 68-W6-0029

September 1998

TABLE OF CONTENTS

EXECUTIVE SUMMARY: BACKGROUND AND FINDINGS

An important environmental challenge facing the United States (US) is management of municipal solid waste (MSW). In 1996, the US generated 210 million tons of MSW;[1] per-capita MSW generation rates have risen throughout most of the last decade. At the same time, the US recognizes climate change as a potentially serious issue, and is embarking on a number of actions to reduce the emissions of greenhouse gases (GHGs) that can cause it. This report examines how the two issues – MSW management and climate change – are related, by presenting material-specific GHG emission factors for various waste management options.

Among the efforts to slow the potential for climate change are measures to reduce emissions of carbon dioxide from energy use, reduce methane emissions, and change forestry practices to promote long-term storage of carbon in trees. Different management options for MSW provide many opportunities to affect these same processes, directly or indirectly. This report integrates, for the first time, a wealth of information on GHG implications of various MSW management options for some of the most common materials in MSW and for mixed MSW and mixed recyclables. The report's findings may be used to support voluntary reporting of emission reductions from waste management practices.

ES.1 GREENHOUSE GASES AND CLIMATE CHANGE

Climate change is a serious international environmental concern and the subject of much research and debate. Many, if not most, of the readers of this report will have a general understanding of the greenhouse effect and climate change. However, for those who are not familiar with the topic, a brief explanation follows.[2]

A naturally occurring shield of "greenhouse gases" (primarily water vapor, carbon dioxide, methane, and nitrous oxide), comprising 1 to 2 percent of the Earth's atmosphere, traps radiant heat from the Earth and helps warm the planet to a comfortable, livable temperature range. Without this natural "greenhouse effect," the average temperature on Earth would be approximately 5 degrees Fahrenheit, rather than the current 60 degrees Fahrenheit.[3]

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[1] U.S. EPA Office of Solid Waste, *Characterization of Municipal Solid Waste in the United States: 1997 Update*, EPA 530-R-9-001, p. 26.

[2] For more detailed information on climate change, please see *The Draft 1998 Inventory of US Greenhouse Gas Emissions and Sinks: 1990-1996*, (http://www.epa.gov/globalwarming/inventory/1998-inv.html) (March 1998); and *Climate Change 1995: The Science of Climate Change* (J.T. Houghton, *et al.*, eds.; Intergovernmental Panel on Climate Change [IPCC]; published by Cambridge University Press, 1996). To obtain a list of additional documents addressing climate change, call EPA's Climate Change "FAX on Demand" at (202) 260-2860 or access EPA's global warming web site at www.epa.gov/globalwarming.

[3] *Climate Change 1995: The Science of Climate Change* (*op. cit.*), pp. 57-58.

Many scientists, however, are alarmed by a significant increase in the concentration of carbon dioxide and other GHGs in the atmosphere. Since the pre-industrial era, atmospheric concentrations of carbon dioxide have increased by nearly 30 percent and methane concentrations have more than doubled. There is a growing international scientific consensus that this increase has been caused, at least in part, by human activity, primarily the burning of fossil fuels (coal, oil, and natural gas) for such activities as generating electricity and driving cars.[4]

Moreover, there is a growing consensus in international scientific circles that the buildup of carbon dioxide and other GHGs in the atmosphere will lead to major environmental changes such as: (1) rising sea levels (that may flood coastal and river delta communities); (2) shrinking mountain glaciers and reduced snow cover (that may diminish fresh water resources), (3) the spread of infectious diseases and increased heat-related mortality, (4) impacts to ecosystems and possible loss in biological diversity, and (5) agricultural shifts such as impacts on crop yields and productivity. Although it is difficult to reliably detect trends in climate due to natural variability, the best current predictions suggest that the rate of climate change attributable to GHGs will far exceed any natural climate changes that have occurred during the last 10,000 years.[5]

Many of these changes appear to be occurring already. Global mean surface temperatures have already increased by about 1 degree Fahrenheit over the past century. A reduction in the Northern Hemisphere's snow cover, a decrease in Arctic sea ice, a rise in sea level, and an increase in the frequency of extreme rainfall events have all been documented.[6]

Such important environmental changes pose potentially significant risks to humans, social systems, and the natural world. Of course, many uncertainties remain regarding the precise timing, magnitude, and regional patterns of climate change and the extent to which mankind and nature can adapt to any changes. It is clear, however, that changes will not be easily reversed for many decades or even centuries because of the long atmospheric lifetimes of the GHGs and the inertia of the climate system.

ES.2 WHAT IS THE UNITED STATES DOING ABOUT CLIMATE CHANGE?

In 1992, world leaders and citizens from some 200 countries met in Rio de Janeiro, Brazil to confront global ecological concerns. At this "Earth Summit", 154 nations, including the United States, signed the Framework Convention on Climate Change, an international agreement to address the danger of global climate change. The objective of the Convention is to stabilize GHG concentrations in the atmosphere at a level, and over a time frame, that will minimize man-made climate disruptions.

By signing the Convention, countries make a voluntary commitment to reduce GHGs or take other actions to stabilize emissions of GHGs at 1990 levels. All parties to the Convention are also required to develop, and periodically update, national inventories of their GHG emissions. The US ratified the Convention in October 1992. One year later, President Clinton issued the US *Climate Change Action Plan* (CCAP), which called for cost-effective domestic

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[4] *Ibid.*, pp. 3-5.

[5] *Ibid.*, pp. 6, 29-30, 156, and 371-372.

[6] *Ibid.*, pp. 26, 29-30, 156, and 171.

actions and voluntary cooperation with states, local governments, industry, and citizens to reduce GHG emissions.

Countries that ratified the Framework Convention on Climate Change met in Kyoto, Japan in December 1997, where they agreed to reduce global greenhouse gas emissions and set binding targets for developed nations. (For example, the emissions target for the US would be 7 percent below 1990 levels.) As of the publication of this report, the Kyoto agreement remains to be signed by the President and ratified by the US Senate; meanwhile, EPA continues to promote voluntary measures to reduce GHG emissions begun under the CCAP. The countries that ratified the Framework Convention will meet again in Buenos Aires in November, 1998, where the US will attempt to secure meaningful participation by developing countries.

The CCAP outlines over 50 voluntary initiatives to reduce GHG emissions in the US. One of the initiatives calls for *accelerated source reduction and recycling of municipal solid waste* through combined efforts by EPA, the Department of Energy, and the Department of Agriculture. Another waste related initiative is the Landfill Methane Outreach Program, which aims to reduce landfill methane emissions by facilitating the development of landfill gas utilization projects.[7]

ES.3 WHAT IS THE RELATIONSHIP OF MUNICIPAL SOLID WASTE TO GREENHOUSE GAS EMISSIONS?

What does municipal solid waste have to do with rising sea levels, higher temperatures, and GHG emissions? For many wastes, the materials that we dispose represent what is left over after a long series of steps including: (1) extraction and processing of raw materials; (2) manufacture of products; (3) transportation of materials and products to markets; (4) use by consumers; and (5) waste management.

At virtually every step along this "life cycle," the potential exists for GHG impacts. Waste management affects GHGs by affecting one or more of the following:

(1) <u>Energy consumption</u> (specifically, combustion of fossil fuels) associated with making, transporting, using, and disposing the product or material that becomes a waste.

(2) <u>Non-energy-related manufacturing emissions</u>, such as the carbon dioxide released when limestone is converted to lime (which is needed for aluminum and steel manufacturing).

(3) <u>Methane emissions</u> from landfills where the waste is disposed.

(4) <u>Carbon sequestration</u>, which refers to natural or man-made processes that remove carbon from the atmosphere and store it for long time periods or permanently. A store of sequestered carbon (e.g., a forest or coal deposit) is known as a carbon sink.

[7] The Landfill Methane Outreach Program is a voluntary partnership between the EPA, state agencies, landfill gas-to-energy developers and energy users. The program has an Internet home page (http://www.epa.gov/landfill.html), and can be reached via a toll-free hotline number (1-800-782-7937).

The first three mechanisms add GHGs to the atmosphere and contribute to global warming. The fourth – carbon sequestration – reduces GHG concentrations by removing carbon dioxide from the atmosphere. Forests are one mechanism for sequestering carbon; if more wood is grown than is removed (through harvest or decay), the amount of carbon stored in trees increases, and thus carbon is sequestered.

Different wastes and waste management options have different implications for energy consumption, methane emissions, and carbon sequestration. Source reduction and recycling of paper products, for example, reduce energy consumption, decrease combustion and landfill emissions, and increase forest carbon sequestration.

ES.4 WHY EPA PREPARED THIS REPORT AND HOW IT WILL BE USED

Recognizing the potential for source reduction and recycling of municipal solid waste to reduce GHG emissions, EPA included a source reduction and recycling initiative in the original 1994 CCAP. At that time, EPA estimated that its portion of the source reduction and recycling initiative could reduce annual GHG emissions by roughly 5.6 million metric tons of carbon equivalent (MTCE) by the year 2000, or about 5 percent of the overall goal of the Action Plan. To make these projections, EPA used limited data on energy consumption and forest carbon sequestration to estimate how a 5 percent increase in both source reduction and recycling would affect GHG emissions in 2000.

It was clear then that a rigorous analysis would be needed to more accurately gauge the total GHG emission reductions achievable through source reduction and recycling. Moreover, it was clear that all of the options for managing MSW should be considered. By addressing a broader set of MSW management options, a more comprehensive picture of the GHG benefits of voluntary actions in the waste sector could be determined and the relative GHG impacts of various waste management approaches could be assessed. To this end, the Office of Policy and the Office of Solid Waste launched a major research effort.

This research effort has been guided by contributions from many reviewers participating in three review cycles (as described in Background Document C). The first draft report was reviewed in 1995 by 20 EPA analysts from four offices (Air and Radiation; Policy; Research and Development; and Solid Waste) as well as analysts from the US Department of Energy and US Department of Agriculture, Forest Service. Comments resulting from these reviews were incorporated into a second draft of the report, completed in May 1996.

The 1996 draft was distributed to four researchers with academic and consulting backgrounds for a more intensive, external peer review. Based on their comments, another draft of the report was completed in March of 1997.

In March, 1997, EPA published the draft research in a report entitled *Greenhouse Gas Emissions from Municipal Waste Management: Draft Working Paper* (EPA530-R-97-010). As described in an accompanying Federal Register notice, public comment was solicited on the draft working paper.

This final report reflects comments from 23 individuals, representing trade associations, universities, industry, state offices, EPA offices, and other entities. Among the groups that provided detailed comments were:

- The American Forest and Paper Association,
- The American Plastics Council,
- The Steel Recycling Institute,
- The Integrated Waste Services Association,
- The Minnesota Office of Environmental Assistance, and
- The Missouri Department of Natural Resources.

Each comment on the draft working paper is specifically discussed in a comment response document, which is available in the public docket (F-97-GGEA-FFFFF). For each comment received, the comment response document summarizes both the comment and EPA's response. Among the changes made as a result of this review, EPA

- added two materials to the analysis—mixed paper and glass,
- revised system efficiencies for waste combustors, and provided a separate characterization of refuse-derived fuel (RDF) as a category of combustion,
- based GHG reductions from displaced electricity on GHGs from fossil-fuel-fired generation, rather than from the national average mix of fuels.

Each of these changes is discussed in more detail later in this report. In addition, this report updates many of the inputs to the calculations (such as the global warming potential for various greenhouse gases), and uses more recent information on waste composition and recycling rates.

The primary application of the GHG emission factors in this report is to support climate change mitigation accounting for waste management practices. Organizations interested in quantifying and voluntarily reporting GHG emission reductions associated with waste management practices may use these emission factors for that purpose. In conjunction with the Department of Energy, EPA has used these emission factors to develop guidance for voluntary reporting of GHG reductions, as authorized by Congress in Section 1605 (b) of the Energy Policy Act of 1992. EPA also plans to use these emission factors to evaluate its progress in reducing US GHG emissions—by promoting source reduction and recycling through voluntary programs such as WasteWi$e and Pay-as-You-Throw (PAYT)—as part of the US CCAP. The methodology presented in this report may also assist other countries involved in developing GHG emissions estimates for their solid waste streams.[8]

ES.5 HOW WE ANALYZED THE IMPACT OF MUNICIPAL SOLID WASTE ON GREENHOUSE GAS EMISSIONS

To measure the GHG impacts of municipal solid waste (MSW), one must first decide which wastes to analyze. We surveyed the universe of materials and products found in MSW and determined which were most likely to have the greatest impact on GHGs. These determinations were based on (1) the quantity generated, (2) differences in energy use for manufacturing a product from virgin versus recycled inputs, and (3) the potential contribution of materials to methane generation in landfills. By this process, we limited the analysis to the following 11 items:

[8] Note that waste composition and product life cycles vary significantly among countries. This report may assist other countries by providing a methodologic framework and benchmark data for developing GHG emission estimates for their solid waste streams.

- newspaper,
- office paper,
- corrugated cardboard,
- aluminum cans,
- steel cans,
- glass containers,
- HDPE (high density polyethylene) plastic,
- LDPE (low density polyethylene) plastic,
- PET (polyethylene terephthalate) plastic,
- food scraps, and
- yard trimmings.

The foregoing materials constitute 55 percent, by weight, of municipal solid waste, as shown in Exhibit ES-1.[9] We also examined the GHG implications of managing mixed MSW, mixed recyclables, and mixed paper.

Exhibit ES-1
Percentage of 1996 US Generation of MSW for Materials in This Report

Material	Percentage of MSW Generation (by Weight)
Newspaper	5.9%
Office paper	3.2%
Corrugated cardboard	13.8%
Aluminum cans	0.8%
Steel cans	1.3%
Glass containers	5.3%
HDPE plastic*	0.6%
LDPE plastic*	0.01%
PET plastic*	0.5%
Food scraps	10.4%
Yard trimmings	13.4%
TOTAL	55%

Source: Franklin Associates, Ltd., *Characterization of Municipal Solid Waste in the United States: 1997 Update*. EPA 530-R-98-007 (May 1998)
* Based on blow-molded containers.

- *Mixed MSW* is comprised of the waste material typically discarded by households and collected by curbside collection vehicles; it does not include white goods or industrial waste. This report analyzes mixed MSW on an "as disposed" (rather than "as generated") basis.
- *Mixed recyclables* are materials that are typically recycled. As used in this report, the term includes the items listed in Exhibit ES-1, except food scraps and yard trimmings. The emission factors reported for mixed recyclables represent the average GHG emissions for these materials, weighted by the tonnages at which they are recycled.
- *Mixed paper* is recycled in large quantities, and is an important class of scrap material in many recycling programs. However, it is difficult to present a single definition of mixed paper because each mill using recovered paper defines its own supply which varies with the availability and price of different grades of paper. Therefore, for purposes of this report, we identified three different definitions for

[9] Note that these data are based on national averages. The composition of solid waste varies locally and regionally; local or state-level data should be used when available. In recognition of the variability in local conditions, EPA is developing the WAste Reduction Model (WARM), which may be used to estimate the GHG emissions of MSW management actions on a local and state level. For more information on the WARM model, contact the RCRA Hotline at 1-800-424-9346.

mixed paper according to their dominant source—broad (general sources), office, and residential.

Next, we developed a streamlined life cycle inventory for each of the selected materials. Our analysis is streamlined in the sense that it examines GHG emissions only, and is not a more comprehensive environmental analysis of all emissions from municipal solid waste management options.[10]

We focused on those aspects of the life cycle that have the potential to emit GHGs as materials change from their raw states, to products, to waste. Exhibit ES-2 shows the steps in the life cycle at which GHGs are emitted, carbon sequestration is affected, and utility energy is displaced. As shown, we examined the potential for these effects at the following points in a product's life cycle:

- raw material acquisition (fossil fuel energy and other emissions, and change in forest carbon sequestration);
- manufacturing (fossil fuel energy emissions); and
- waste management (carbon dioxide emissions associated with combustion and methane emissions from landfills; these emissions are offset to some degree by avoided utility fossil fuel use and carbon sequestration in landfills).

At each of these points, we also considered transportation-related energy emissions.

GHG emissions associated with electricity used in the raw materials acquisition and manufacturing steps are estimated based on the current mix of energy sources, including fossil fuels, hydropower, and nuclear power. However, estimates of GHG emission reductions attributable to utility emissions avoided from waste management practices are based solely on the reduction of fossil fuel use.[11]

We did not analyze the GHG emissions associated with consumer use of products because energy use for the selected materials is small (or zero) at this point in the life cycle. In addition, the energy consumed during use would be approximately the same whether the product was made from virgin or recycled inputs.

To apply the GHG estimates developed in this report, one must compare a baseline scenario with an alternative scenario, on a life-cycle basis. For example, one could compare a baseline scenario, where 10 tons of office paper is manufactured, used, and landfilled, to an alternative scenario, where 10 tons is manufactured, used, and recycled.

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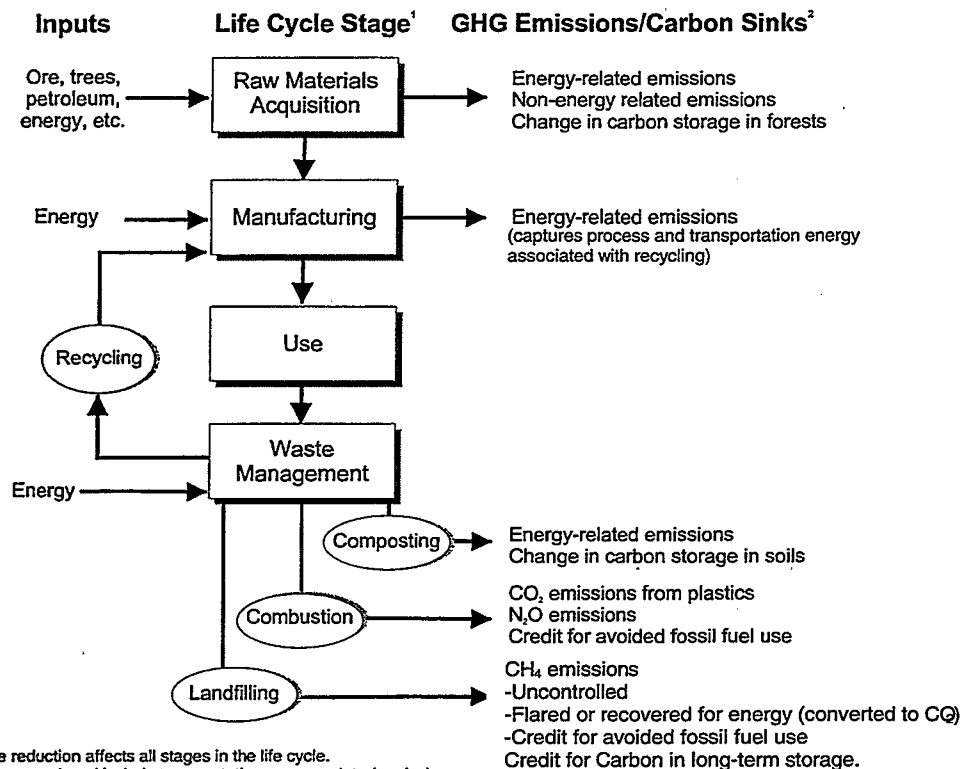
[10] EPA's Office of Research and Development (ORD) is performing a more extensive application of life cycle assessment for various waste management options for MSW. ORD's analysis will inventory a broader set of emissions (air, water, and waste) associated with these options. For more information on this effort, go to their project website at http://www.epa.gov/docs/crb/apb/apb.htm.

[11] We adopted this approach based on suggestions from several commenters who argued that fossil fuels should be regarded as the marginal fuel displaced by waste-to-energy and landfill gas recovery systems.

Exhibit ES-2
GHG Sources and Sinks Associated with Materials in the MSW Stream



[1]Note that source reduction affects all stages in the life cycle.
[2]All life cycle stages analyzed include transportation energy-related emissions.

In calculating emissions for the scenarios, two different reference points can be used:

- With a "raw material extraction" reference point (i.e., cradle-to-grave perspective), one can start at the point of raw material acquisition as the "zero point" for emissions, and add all emissions (and deduct sinks) from that point on through the life cycle.
- With a "waste generation" reference point (solid waste manager's perspective), one can begin accounting for GHG emissions at the point of waste generation. All subsequent emissions and sinks from waste management practices are then accounted for. Changes in emissions and sinks from raw material acquisition and manufacturing processes are captured to the extent that certain waste management practices (i.e., source reduction and recycling) impact these processes.

When developing an emission factor to account for GHG emissions from a waste management activity, the key question to ask is "What is the baseline management practice?" Because it is the difference in emissions between the baseline and alternate scenarios that is meaningful, using raw material extraction or waste generation reference points yields the same results. The March 1997 Draft Working Paper used the raw material extraction reference point to display GHG emissions because it is most consistent with standard life cycle inventory accounting techniques. Several commenters pointed out that solid waste decision-makers tend to view raw materials acquisition and manufacturing as beyond their control, and suggested that a waste generation GHG accounting approach would provide more clarity for evaluating waste management options. Thus, this report uses the waste generation approach, and defines a standard raw material acquisition and manufacturing step for each material as consisting of average GHG emissions based on the current mix of virgin and recycled inputs. This standard raw material acquisition and manufacturing step is used to estimate the upstream impacts of source reduction and recycling.

Exhibit ES-3 shows how the GHG sources and sinks are affected by each waste management strategy using the waste generation reference point. For example, the top row of the exhibit shows that source reduction[12] (1) reduces GHG emissions from raw materials acquisition and manufacturing; (2) results in an increase in forest carbon sequestration; and (3) does not result in GHG emissions from waste management. The sum of emissions (and sinks) across all steps in the life cycle represents net emissions.

[12] In this analysis, the source reduction techniques we analyze involve using less of a given product without using more of some other product – e.g., making aluminum cans with less aluminum ("lightweighting"); double-sided rather than single-sided photocopying; or reuse of a product. We did not consider source reduction of one product that would be associated with substitution by another product – e.g., substituting plastic boxes for corrugated paper boxes. Nor did we estimate the potential for source reduction of chemical fertilizers and pesticides with increased production and use of compost. For a discussion of source reduction with material substitution, please see section 4.3.

Exhibit ES-3
Components of Net Emissions for Various Municipal Solid Waste Management Strategies

Municipal Solid Waste Management Strategy	Greenhouse Gas Sources and Sinks: Raw Materials Acquisition and Manufacturing	Change in Forest or Soil Carbon Storage	Waste Management
Source Reduction	Decrease in GHG emissions, relative to the baseline of manufacturing	Increase in forest carbon storage	No emissions/sinks
Recycling	Decrease in GHG emissions due to lower energy requirements (compared to manufacture from virgin inputs) and avoided process non-energy GHGs	Increase in forest carbon storage	Process and transportation emissions associated with recycling are counted in the manufacturing stage
Composting (food scraps, yard trimmings)	No emissions/sinks	Increase in soil carbon storage	Compost machinery emissions and transportation emissions
Combustion	No change	No change	Nonbiogenic CO_2, N_2O emissions, avoided utility emissions, and transportation emissions
Landfilling	No change	No change	Methane emissions, long-term carbon storage, avoided utility emissions, and transportation emissions

ES.6 RESULTS OF THE ANALYSIS

Management of municipal solid waste presents many opportunities for GHG emission reductions. Source reduction and recycling can reduce GHG emissions at the manufacturing stage, increase forest carbon storage, and avoid landfill methane emissions. When waste is combusted, energy recovery displaces fossil fuel-generated electricity from utilities (thus reducing GHG emissions from the utility sector), and landfill methane emissions are avoided. Landfill methane emissions can be reduced by using gas recovery systems and by diverting organic materials from the landfill.

In order to support a broad portfolio of climate change mitigation activities covering a broad scope of greenhouse gases, many different emission estimation methodologies will need to be employed. The primary result of this research is the development of material-specific GHG emission factors which can be used to account for the climate change benefits of waste management practices. A spreadsheet accounting tool, the Waste Reduction Model (WARM), is being developed to allow for customizing of emission factors based on key variables which may better reflect local conditions.

Exhibit ES-4 presents the GHG impacts of source reduction, recycling, composting, combustion, and landfilling, on a per-ton managed basis, for the individual materials, mixed waste, and mixed recyclables, using the waste generation reference point. For comparison, Exhibit ES-5 shows the same results, using the raw material extraction reference point. In these tables, emissions for one ton of a given material are presented across different management options.[13] The life cycle GHG emissions for each of the first four waste management strategies – source reduction, recycling, composting, and combustion – are compared to the GHG emissions from landfilling in Exhibit ES-6. This exhibit shows the GHG values for each of the first four management strategies, minus the GHG values for landfilling. With this exhibit, one may compare the GHG emissions of changing management of one ton of each material from landfilling (often viewed as the baseline waste management strategy) to one of the other waste management options.

All values shown in Exhibit ES-4 through ES-6 are for national average conditions (e.g., average fuel mix for raw material acquisition and manufacturing using recycled inputs; typical efficiency of a mass burn combustion unit; national average landfill gas collection rates). GHG emissions are sensitive to some factors that vary on a local basis, and thus site-specific emissions willdiffer from those summarized here.

Following is a discussion of the principal GHG emissions and sinks for each waste management practice and effect they have on the emission factors:

- Source reduction, generally speaking, represents an opportunity to reduce GHG emissions in a significant way.[14] The reduction in energy-related CO_2 emissions from the raw material acquisition and manufacturing process, and the absence of emissions from waste management, combine to reduce GHG emissions more than all other options.
- Recycling generally has the second lowest GHG emissions. For most materials, recycling reduces enery-related CO_2 emissions in the manufacturing process (although not as dramatically as source reduction) and avoids emissions from waste management. Paper recycling increase storage of forest carbon.

[13] Note that the difference between any two values for a given material in Exhibit ES-4 (i.e., emissions for the same material in two waste management options) is the same as the difference between the two corresponding values in Exhibit ES-5.

[14] As noted above, the only source reduction strategy analyzed in this study is lightweighting. Consequently, the results shown here do not directly apply to material substitution.

Exhibit ES-4

Net GHG Emissions from Source Reduction and MSW Management Options

Emissions Counted from a Waste Generation Reference Point (MTCE/Ton)[1]

Material	Source Reduction[2]	Recycling	Composting[3]	Combustion[4]	Landfilling[5]
Newspaper	-0.91	-0.86	NA	-0.22	-0.23
Office Paper	-1.03	-0.82	NA	-0.19	0.53
Corrugated Cardboard	-0.78	-0.70	NA	-0.19	0.04
Mixed Paper					
Broad Definition	NA	-0.67	NA	-0.19	0.06
Residential Definition	NA	-0.67	NA	-0.19	0.03
Office Paper Definition	NA	-0.84	NA	-0.18	0.10
Aluminum Cans	-2.98	-3.88	NA	0.03	0.01
Steel Cans	-0.84	-0.57	NA	-0.48	0.01
Glass	-0.14	-0.08	NA	0.02	0.01
HDPE	-0.61	-0.37	NA	0.21	0.01
LDPE	-0.89	-0.49	NA	0.21	0.01
PET	-0.98	-0.62	NA	0.24	0.01
Food Scraps	NA	NA	0.00	-0.05	0.15
Yard Trimmings	NA	NA	0.00	-0.07	-0.11
Mixed MSW as Disposed	NA	NA	NA	-0.04	-0.02
Mixed Recyclables	NA	-0.76	NA	-0.18	0.03

Note that totals may not add due to rounding and more digits may be displayed than are significant.

NA: Not applicable, or in the case of composting of paper, not analyzed.

[1]MTCE/ton: Metric tons of carbon equivalent per short ton of material. Material tonnages are on an as-managed (wet weight) basis.

[2]Source reduction assumes initial production using the current mix of virgin and recycled inputs.

[3]There is considerable uncertainty in our estimate of net GHG emissions from composting; the values of zero are plausible values based on assumptions and a bounding analysis.

[4]Values are for mass burn facilities with national average rate of ferrous recovery.

[5]Values reflect projected national average methane recovery in year 2000.

Exhibit ES-5
Net GHG Emissions from Source Reduction and MSW Management Options
Emissions Counted from a Raw Materials Extraction Reference Point (MTCE/Ton)

Material	Source Reduction[1]	Recycling[2]	Composting[2]	Combustion[2]	Landfilling[2]
Newspaper	-0.43	-0.38	NA	0.26	0.25
Office Paper	-0.50	-0.30	NA	0.34	1.06
Corrugated Cardboard	-0.38	-0.30	NA	0.21	0.44
Mixed Paper					
Broad Definition	NA	-0.21	NA	0.26	0.51
Residential Definition	NA	-0.22	NA	0.26	0.48
Office Paper Definition	NA	-0.33	NA	0.33	0.61
Aluminum Cans	0.00	-0.90	NA	3.01	3.00
Steel Cans	0.00	0.26	NA	0.35	0.85
Glass	0.00	0.06	NA	0.17	0.15
HDPE	0.00	0.24	NA	0.81	0.62
LDPE	0.00	0.40	NA	1.10	0.90
PET	0.00	0.36	NA	1.21	0.99
Food Waste	NA	NA	0.00	-0.05	0.15
Yard Waste	NA	NA	0.00	-0.07	-0.11
Mixed MSW as Disposed	NA	NA	NA	-0.04	-0.02
Mixed Recyclables	NA	-0.26	NA	0.33	0.53

Note that totals may not add due to rounding and more digits may be displayed than are significant.

NA: Not applicable, or in the case of composting of paper, not analyzed.

[1] Source reduction assumes initial production using the current mix of virgin and recycled inputs.

[2] Includes emissions from the initial production of the material being managed, except for food waste, yard waste, and mixed MSW.

Exhibit ES-6
Greenhouse Gas Emissions of MSW Management Options Compared to Landfilling[1]
(MTCE/Ton)

Material	Source Reduction[2] Net Emissions Minus Landfilling Net Emissions	Recycling Net Emissions Minus Landfilling Net Emissions	Composting[3] Net C Minus Landfilling Net Emissions	Combustion[4] Net Emissions Minus Landfilling Net Emissions
Newspaper	-0.68	-0.63	NA	0.01
Office Paper	-1.56	-1.35	NA	-0.72
Corrugated Cardboard	-0.82	-0.74	NA	-0.23
Mixed Paper				
Broad Definition	NA	-0.73	NA	-0.25
Residential Definition	NA	-0.69	NA	-0.22
Office Paper Definition	NA	-0.95	NA	-0.28
Aluminum Cans	-3.00	-3.89	NA	0.02
Steel Cans	-0.85	-0.58	NA	-0.49
Glass	-0.15	-0.09	NA	0.01
HDPE	-0.62	-0.38	NA	0.20
LDPE	-0.90	-0.51	NA	0.20
PET	-0.99	-0.63	NA	0.22
Food Scraps	NA	NA	-0.15	-0.20
Yard Trimmings	NA	NA	0.11	0.04
Mixed MSW as Disposed	NA	NA	NA	-0.02
Mixed Recyclables	NA	-0.79	NA	-0.20

Note that totals may not add due to rounding and more digits may be displayed than are significant.

NA: Not applicable, or in the case of composting of paper, not analyzed.

[1]Values for landfilling reflect projected national average methane recovery in year 2000.

[2]Source reduction assumes initial production using the current mix of virgin and recycled inputs.

[3]Calculation is based on assuming zero net emissions for composting.

[4]Values are for mass burn facilities with national average rate of ferrous recovery.

- Composting is a management option for food scraps and yard trimmings. The net GHG emissions from composting are lower than landfilling for food scraps (composting avoids methane emissions), and higher than landfilling for yard trimmings (landfilling is credited with the carbon storage that results from failure of certain yard trimmings to degrade fully in landfills). Overall, given the uncertainty in the analysis, the emission factors for composting or combusting these materials are similar.

- The net GHG emissions from combustion and landfilling are similar for mixed MSW. Because, in practice, combustors and landfills manage a mixed wastestream, net emissions are determined more by technology factors (e.g., landfill gas collection system efficiency, combustion energy conversion efficiency) than by material specificity. Material-specific emissions for landfills and combustors provide a basis for comparing these options with source reduction, recycling, and composting.

The ordering of combustion, landfilling, and composting is affected by (1) the GHG inventory accounting methods, which do not count CO_2 emissions from sustainable biogenic sources,[15] but do count emissions from sources such as plastics, and (2) a series of assumptions on sequestration, future use of methane recovery systems, landfill gas recovery system efficiency, ferrous metals recovery, and avoided utility fossil fuels. On a site-specific basis, the ordering of results between a combustor and a landfill could be different from the ordering provided here, which is based on national average results.

We conducted sensitivity analyses to examine the GHG emissions from landfilling under varying assumptions about (1) the percentage of landfilled waste sent to landfills with gas recovery and (2) methane oxidation rate and gas collection system efficiency. The sensitivity analyses demonstrate that the results for landfills are very sensitive to these factors, which are site-specific.[16] Thus, using a national average value when making generalizations about emissions from landfills masks some of the variability that exists from site to site.

The scope of this report is limited to developing emission factors that can be used to evaluate GHG implications of solid waste decisions. We do not analyze policy options in this report. Nevertheless, the differences in emission factors across various waste management options are sufficiently large as to imply that GHG mitigation policies in the waste sector can make a significant contribution to US emission reductions. A number of examples, using the emission factors in this report, bear this out.

- At the firm level, targeted recycling programs can reduce GHGs. For example, a commercial facility that shifts from a baseline practice of landfilling (in a landfill with no gas collection system) to recycling 50 tons office paper and 2 tons of aluminum cans can reduce GHG emissions by over 100 MTCE.

- At the community level, a city of 100,000 with average waste generation (4.3 lb/day per capita) and recycling (27 percent), and baseline disposal in a landfill

[15] Sustainable biogenic sources include paper and wood products from sustainably managed forests; when these materials are burned or aerobically decomposed to CO_2, the CO_2 emissions are not counted. Our approach to measuring GHG emissions from biogenic sources is described in detail in Chapter 1.

[16] For details on the sensitivity analyses, see section 7.4 and Exhibits 7-7 and 7-8.

with no gas collection system, could increase the recycling rate to 40 percent — for example, by implementing a pay-as-you-throw program — and reduce emissions by about 10,000 MTCE per year. (Note that further growth in recycling would be possible; some communities are already exceeding recycling rates of 50 percent).

- A city of 1 million, disposing of 650,000 tons per year in a landfill without gas collection, could reduce GHG emissions by 92,000 MTCE per year by managing waste in a mass burn combustor unit.
- A town of 50,000 landfilling 30,000 tons per year could install a landfill gas recovery system and reduce emissions by about 6,600 MTCE per year.
- At the national level, if the US attains the goal of a 35 percent recycling rate by 2005, emissions will be reduced by over 9 million MTCE per year compared to a baseline where we maintain the current 27 percent recycling rate and use the "national average" landfill for disposal.

ES.7 LIMITATIONS OF THE ANALYSIS

When conducting this analysis, we used a number of analytical approaches and numerous data sources, each with its own limitations. In addition, we made and applied assumptions throughout the analysis. Although these limitations would be troublesome if used in the context of a regulatory framework, we believe that the results are sufficiently accurate to support their use in voluntary programs. Some of the major limitations follow:

- The manufacturing GHG analysis is based on estimated industry averages for energy usage, and in some cases the estimates are based on limited data.[17] In addition, we used values for the average GHG emissions per ton of material produced, not the marginal emission rates per incremental ton produced. In some cases, the marginal emission rates may be significantly different.
- The forest carbon sequestration analysis deals with a very complicated set of interrelated ecological and economic processes. Although the models used represent the state-of-the-art in forest resource planning, their geographic scope is limited—because of the global market for forest products, the actual effects of paper recycling would occur not only in the US but in Canada and other countries. Other important limitations include: (1) the estimate does not include changes in carbon storage in forest soils and forest floors, (2) the model assumes that no forested lands will be converted to non-forest uses as a result of increased paper recycling, and (3) we use a point estimate for forest carbon sequestration, whereas the system of models predicts changing net sequestration over time.
- The composting analysis was limited by the lack of data on methane generation and carbon sequestration resulting from composting; we relied on a theoretical approach to estimate the values.
- The combustion analysis uses national average values for several parameters; variability from site to site is not reflected in our estimate.

[17] When EPA published this report as a draft working paper, the Agency specifically requested that commenters provide data on raw material acquisition and manufacturing. Although several commenters agreed that updated information would be important, none provided such data.

- The landfill analysis (1) incorporates considerable uncertainty on methane generation and carbon sequestration, due to limited data availability, and (2) uses as a baseline landfill methane recovery levels projected for the year 2000.

Finally, through most of the report we express analytical inputs and outputs as point estimates. We recognize that a rigorous treatment of uncertainty and variability would be useful, but in most cases the information needed to treat these in statistical terms is not available. The report includes some sensitivity analyses to illustrate the importance of selected parameters, and expresses ranges for a few other factors such as GHG emissions from manufacturing. We welcome readers to provide better information where it is available; perhaps with additional information, future versions of this report will be able to shed more light on uncertainty and variability. Meanwhile, we caution that the emission factors reported here should be evaluated and applied with an appreciation for the limitations in the data and methods, as described at the end of each chapter.